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HIGH-TEMPERATURE DESALINATION CAPABILITY OF TFC 1501
REVERSE OSMOSIS ELEMENT(U) ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND FORT. H H GOTO

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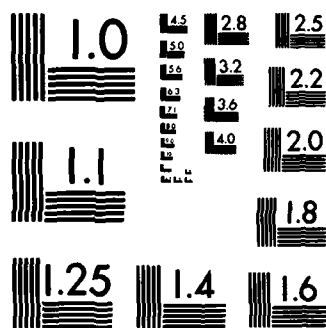
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Report 2367

HIGH-TEMPERATURE DESALINATION CAPABILITY OF
TFC 1501 REVERSE OSMOSIS ELEMENT

by
Haruhiro H. Goto

July 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report covers an investigation conducted to evaluate the desalination capability of TFC 1501 reverse osmosis elements when operated with feedwater the temperature of which is substantially above the maximum operating temperature (113°F) specified by the manufacturer. The results of the investigation indicate: (1) The elements were not degraded in desalinating capability following exposure for 400 h to feedwater at approximately 130°F; (2) the production rate of the elements dropped less than 5 percent following exposure for 400 h to water at approximately 130°F and 200 h at 130°F and 600 lb/in. ²		

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PREFACE

An investigation was conducted to determine the desalination capability of spiral-wound, thin-film composite (TFC) reverse osmosis (RO) elements operated on high-temperature (130°F) saline water. The elements tested were manufactured by UOP, Inc., and were designated TFC 1501. These elements are currently being used in the standard military 600-gal/h reverse osmosis water purification unit (ROWPU). The investigation was conducted under Project 1F464717DL39, "General Support Equipment," during March 1982.

The investigation was conducted by the following personnel of the Petroleum and Environmental Technology Division, Energy and Water Resources Laboratory: Haruhiro H. Goto, Chemical Engineer; Peder B. Pederson, Engineering Technician; and Janet O. Hall, Chemist.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in.	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in. ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
in. ³	cubic inches	16	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	degrees Fahrenheit	5.9 (after subtracting 32)	degrees Celsius	°C

Approximate Conversions
from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in.
cm	centimeters	0.4	inches	in.
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in. ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
ml	milliliters	0.06	cubic inches	in. ³
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F

HIGH-TEMPERATURE DESALINATION CAPABILITY OF TFC 1501 REVERSE OSMOSIS ELEMENT

I. INTRODUCTION

1. Objective. The objective of this investigation was to determine the performance characteristics of reverse osmosis elements (TFC 1501) in an arid region where feedwater temperature could be substantially above the maximum design temperature. These elements are currently being used in the standard military 600-gal/h reverse osmosis water purification units.

2. Background. The investigation covered by this report was conducted as a part of the developmental program for the Army reverse osmosis water purification units. The required operational capability (ROC) for a Family of Water Supply Equipment was approved by Department of the Army on 4 March 1974. The Family of Water Supply Equipment was intended to produce potable water from fresh, brackish, and sea water sources and from water which may be contaminated with nuclear, biological, and chemical (NBC) agents. The family consists of RO units having three different production capacities. The 600-gal/h ROWPU was type-classified on 1 June 1979. The Petroleum and Environmental Technology Division was tasked to develop two larger units; i.e., 3000-gal/h and 1500-gal/h. The TFC 1501 element contains a poly (ether/urea) thin-film semipermeable membrane barrier capable of demineralizing saline water. The production rate of TFC 1501 is highly sensitive to the feedwater temperature. Since the family of equipment must be capable of safe and reliable use in all areas of the world in climatic categories 1,2,5 and 6, as prescribed in Army Regulation 70-38, the RO elements must be capable of handling feedwater having a wide range of temperatures. Figure 1 shows a front view of the 600-gal/h ROWPU and an operator holding a TFC 1501 element.

The study was performed at Building 325, Fort Belvoir, Virginia, during March 1982.

II. INVESTIGATION

3. Equipment. Overall arrangement of the test equipment is shown in Figure 2. Figure 3 shows the high-pressure pump, located outside Building 325 to reduce the noise level. Figure 4 gives the temperature control scheme of the test system. The RO test system, assembled in accordance with the American Society for Testing Materials (ASTM) standard test method (D3736-79), consisted of the following components:

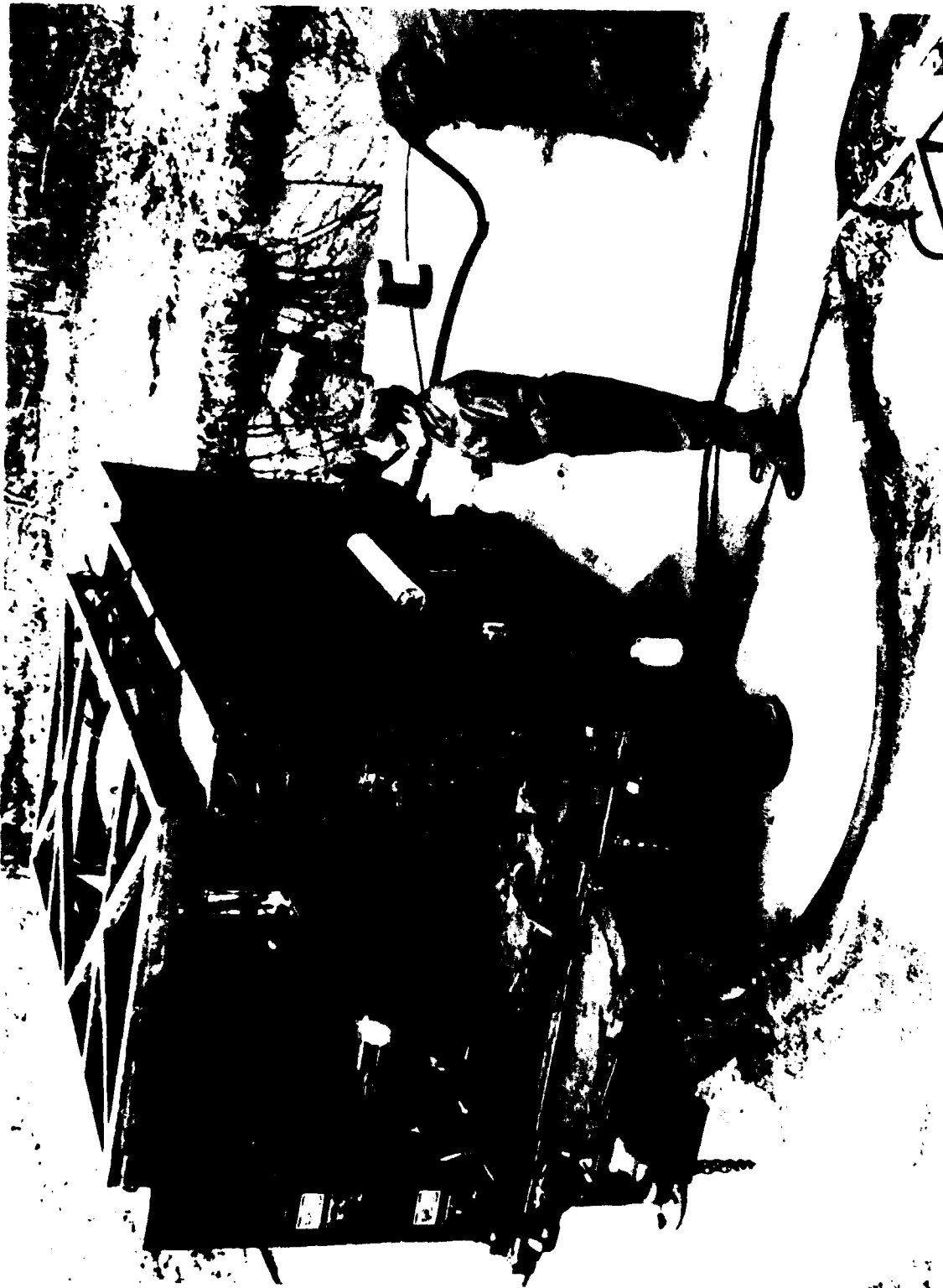


Figure 1. Standard Military 600-gal/h ROWPU.



Figure 2. Equipment layout: (A) booster pump; (B) pressure vessel; (C) turbine flowmeter; (D) conductivity monitor; (E) feedwater tank; (F) pressure gauge; (G) cartridge filter.

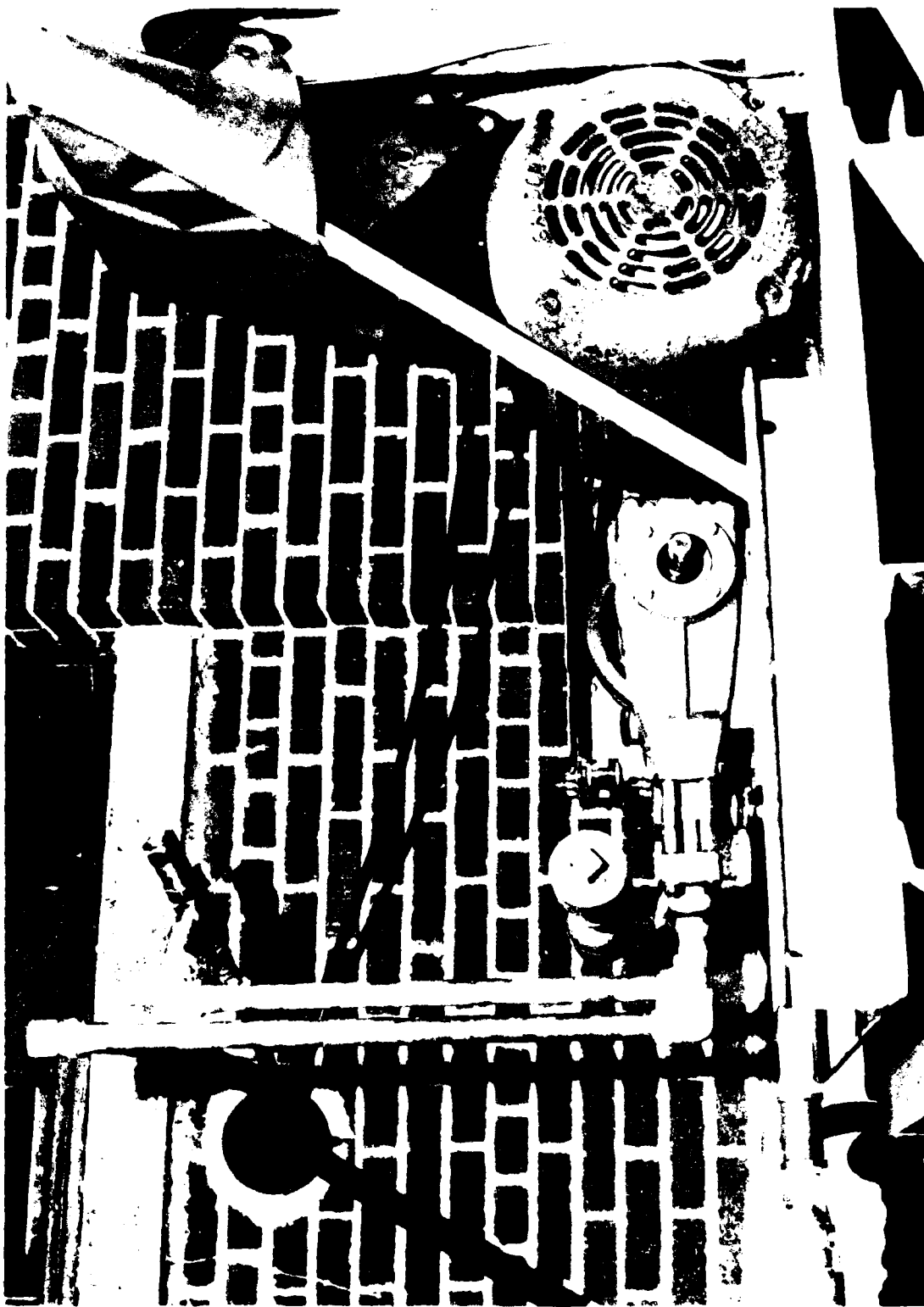


Figure 3. High-pressure pump.

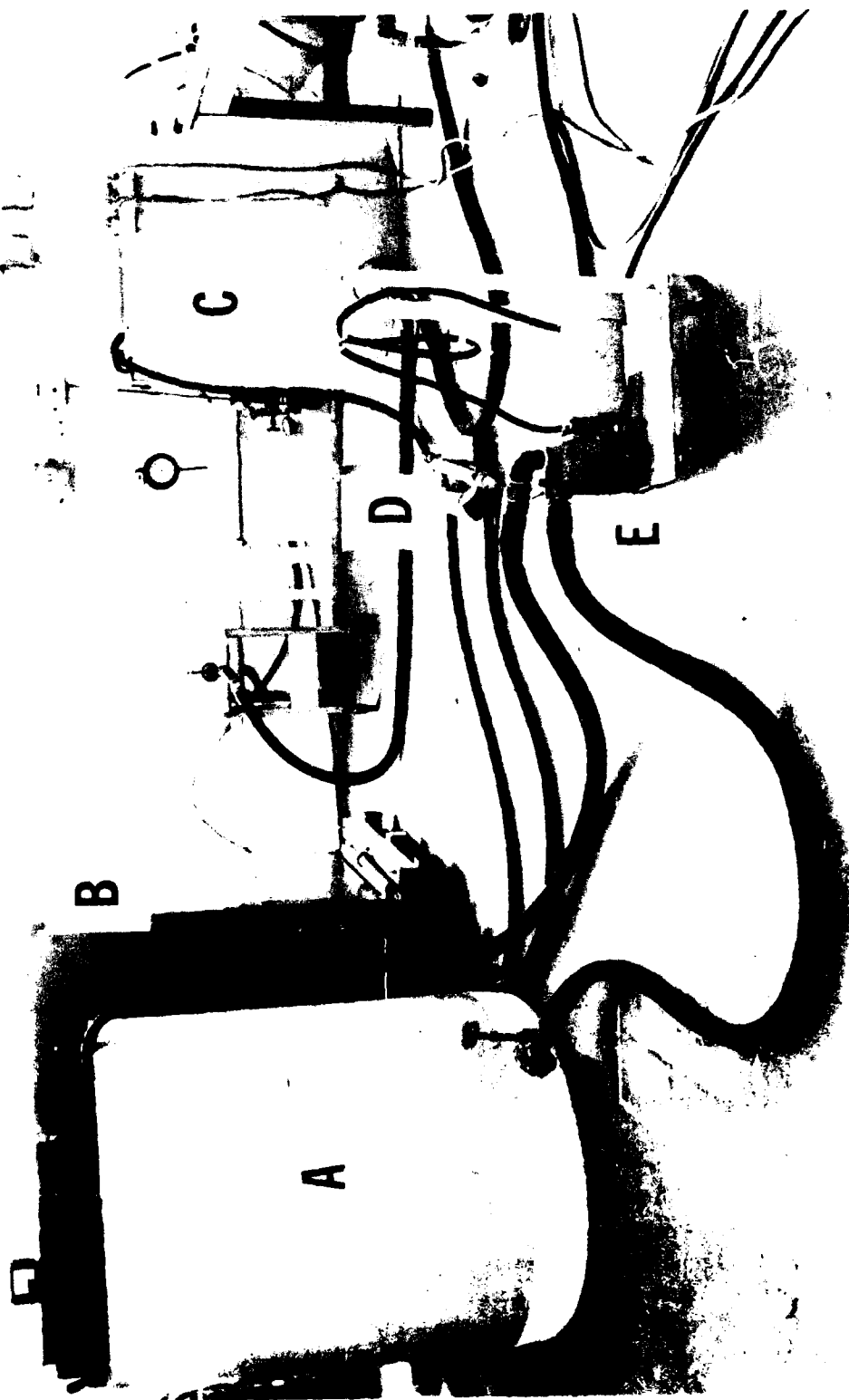


Figure 4. Temperature control arrangement: (A) cooling water tank; (B) chiller; (C) raw water tank; (D) heat exchange; (E) recirculation pump.

- a. One 350-gal polyethylene tank.
- b. One 10-hp chiller to remove excess heat from feedwater.
- c. One stainless steel heat exchanger.
- d. Two immersion heaters.
- e. One 6 FMO Filterite cartridge filter with 5- μ m filter tubes.
- f. One 2020 Cat triplex positive displacement high-pressure pump. The pump capacity is 20 gal/min at 800 lb/in.².
- g. A 66-FRP-Z 6-in. Seawater FRR pressure tube assembly provides a housing for two TFC 1501 6-in.-diameter RO elements.
- h. One 7076 Leeds and Northrup multi-range conductivity monitor to monitor the conductivity of permeate continuously.
- i. One rotometer and one turbine flowmeter to monitor the product flow rate.
- j. Two direct-reading differential pressure flowmeters to monitor the feed and brine flow rates.
- k. Two liquid-filled Marsh pressure gauges to monitor the inlet and outlet pressures of the pressure vessel.
- l. Two AMTEK pressure transducers with a digital readout monitor to monitor the suction and outlet pressures of the high-pressure pump.
- m. Two YSI Tele-Thermometers to monitor the temperature of feedwater and cooling water.
- n. Hose assemblies including necessary fittings and valves to complete the test system.

4. Procedure. The test water was prepared by the addition of evaporated sea salt (99 percent NaCl) to Potomac River water which had been clarified by passage through a pressure diatomaceous earth filter. The total dissolved solids (TDS) of the clarified Potomac River water was brought to approximately 160 mg/l. Analysis of Potomac River water is given in Table 1. Distilled water was added during the study to maintain the water level. The quality of feedwater was maintained by returning the brine and permeate to the feedwater tank, and the TDS for the feedwater was maintained at approximately 26,000 mg/l.

Table 1. Chemical Analysis (14 May 1982)

Characteristic	Potomac River	Feed	Permeate	Brine
pH	7.8	7.6	5.6	7.8
Turbidity (NTU)	3.3	0.3	0.06	0.23
TDS (mg/l)	160	26,186	2,069	31,735
Chlorides (mg/l)	20	15,500	1,230	17,500
Cu (mg/l)	< 0.01	0.20	< 0.01	0.26
Fe (mg/l)	< 0.01	0.10	0.05	0.12

* The RO elements (serial numbers 78690 and 78761) produced by UOP, Inc., were operated initially at 700 lb/in.²g applied pressure and room temperature. As the feedwater temperature was increased to 130°F, the pressure was lowered to 600 lb/in.²g so that the designed production rate of 1.5 gal/min/element would not be exceeded.

The temperature of the feedwater was controlled by a 10-hp Koolant chiller model AF10000. The unit is capable of removing 110,000 Btu of thermal energy in an hour. The cooling water was circulated through the shell side of the stainless steel heat exchanger, while the brine from the pressure vessel was fed into the tube side. Two 3000-W RTC quartz heaters were installed on the feedwater holding tank to raise the feedwater temperature at the beginning of the test.

On the average, the elements were operated for 10 to 12 h/d. For the remainder of the time, the high-temperature feedwater was circulated through the test system by the booster pump. The continuous recirculation was required to maintain the feedwater temperature. As a result, the elements were exposed to the high-temperature feedwater for over 400 h.

The following data were collected hourly during a 200-h high-temperature/high-pressure test period: Applied pressure, product flow rate, brine flow rate, conductivity of feedwater, and conductivity of permeate. The conductivity measurements were made by a Beckman Conductivity Bridge, Model RC 16B (Figure 5). The conductivity readings were calibrated at two temperatures (77°F and 130°F). The calibration curves are presented in Figure 6, and the curves are found to be linear up to TDS of 20,000 mg/l.



Figure 5. Beckman conductivity monitor.

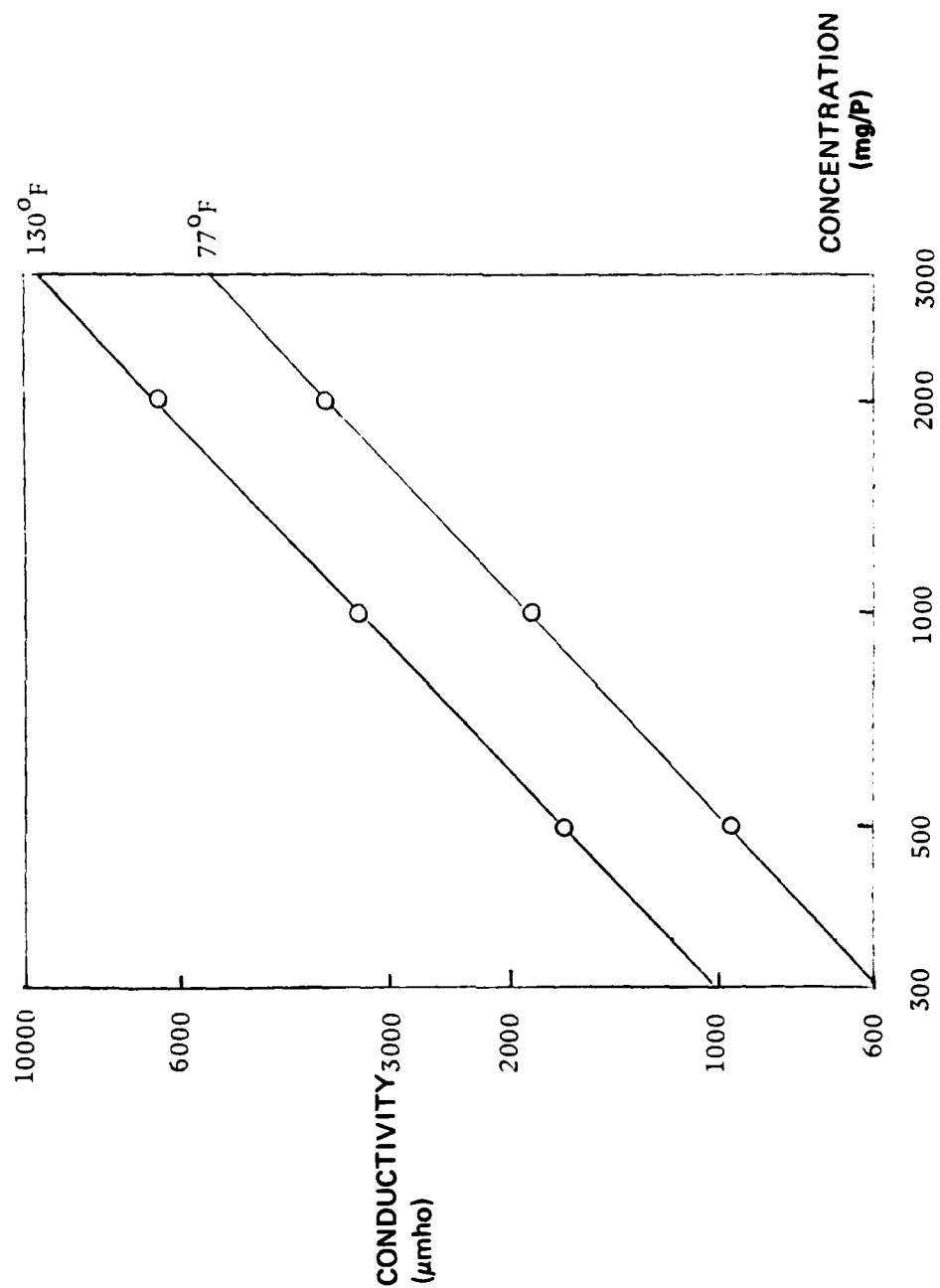


Figure 6. Concentration vs. conductivity.

III. RESULTS

5. Test Data. The results of this investigation are summarized in Tables 1 and 2. The 200-h high-temperature/high-pressure test data are given in the Appendix.

IV. DISCUSSION

6. General. The two TFC 1501 RO elements were operated for 200 h. As indicated in Figure 7, the elements were operated at an applied pressure of 700 lb/in.² for 7 h initially. As the production rate increased with the increase in feed temperature, the operating pressure was lowered to 600 lb/in.² so that the design production rate was maintained. Following the 8 h and 20 min of operation, the feedwater temperature exceeded the maximum design temperature of 113°F. The elements continued to produce at the design production rate (4400 gal/d for two TFC 1501 elements) at elevated temperature (130°F) and a reduced pressure (600 lb/in.²). The recovery rate for the two elements was 14.5 percent of the feedwater rate.

7. Element Performance. As shown in Figure 7, the feedwater temperature rose steadily, surpassing the maximum recommended temperature at the 9-h mark, until it was raised to 129°F. Except for minor variations due to the system limitations, the feedwater temperature was maintained at 130°F for the remainder of the test. Table 3 shows the performance comparison of TFC 1501 elements prior to exceeding the designed feedwater temperature and following the completion of the 200-h high-temperature/high-pressure operation.

As observed in Table 2 and Figure 7, the salt rejection was much higher at higher pressure and lower temperature. This is probably due to the increase in the feedwater temperature, which then increased the salt diffusivity of the TFC membrane. Since the water permeation through the membrane is directly proportional to the pressure difference between the applied pressure and the osmotic pressure of the feedwater, the production rate decreased as the feed pressure was reduced at the 7-h mark. Although the element (serial number 78690) had been slightly telescoped during the high-temperature testing, the subsequent examination of the element at room temperature showed no drop in the desalination capability.

Table 4 shows the results of element performance evaluation conducted following the high-temperature testing. The percent rejections shown in Table 4 are a percent higher than the values given in the Appendix. In the Appendix, percent rejections were calculated using the conductivity readings directly. Although this method is given in the ASTM standard test procedure, more accurate values can be found by avoiding the non-linear region in the conductivity vs. concentration correlation curve.

Table 2. Selected Reverse Osmosis Test Data

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product		Feed Concentration (mg/l)	Product Concentration (mg/l)	Rejection by Conductivity (%)
					Flow Rate (gal/min)	Flow Rate (gal/d)			
3-17	1.0	80	700	17.8	2.8	4,032	23,600	629	97.1
3-17	2.0	82	700	17.8	2.8	4,032	23,600	629	97.1
3-17	3.0	84	700	17.8	2.8	4,032	23,600	629	97.1
3-17	6.0	92	702	17.5	3.0	4,320	23,600	682	96.8
3-17	7.0	100	693	17.3	3.4	4,896	23,600	845	96.1
3-17	8.0	110	586	17.8	2.9	4,176	23,600	1,144	94.8
3-17	9.3	119	580	17.7	3.1	4,464	23,600	1,281	94.1
3-17	11.0	129	568	17.7	3.0	4,320	23,600	1,281	94.1
3-18	20.0	129	604	17.7	3.2	4,608	19,900	918	95.0
3-19	30.0	130	605	17.7	3.2	4,608	17,900	871	94.7
3-20	40.0	129	600	17.6	3.1	4,464	18,600	1,013	94.1
3-21	50.0	129	600	17.6	3.0	4,320	21,600	1,076	94.6
3-23	80.0	129	595	17.8	2.9	4,176	19,200	1,013	94.3
3-25	100.5	130	602	17.5	2.9	4,176	19,900	1,171	93.7
3-29	150.0	132	593	17.6	2.7	3,888	19,200	1,488	91.7
4-3	200.0	131	592	17.6	2.7	3,888	18,200	1,743	90.3
4-3*	200.0	128	600	17.4	2.9	4,176	19,900	1,743	90.7

* Membranes were flushed w/di-stilled water for 2 h prior to data collection.

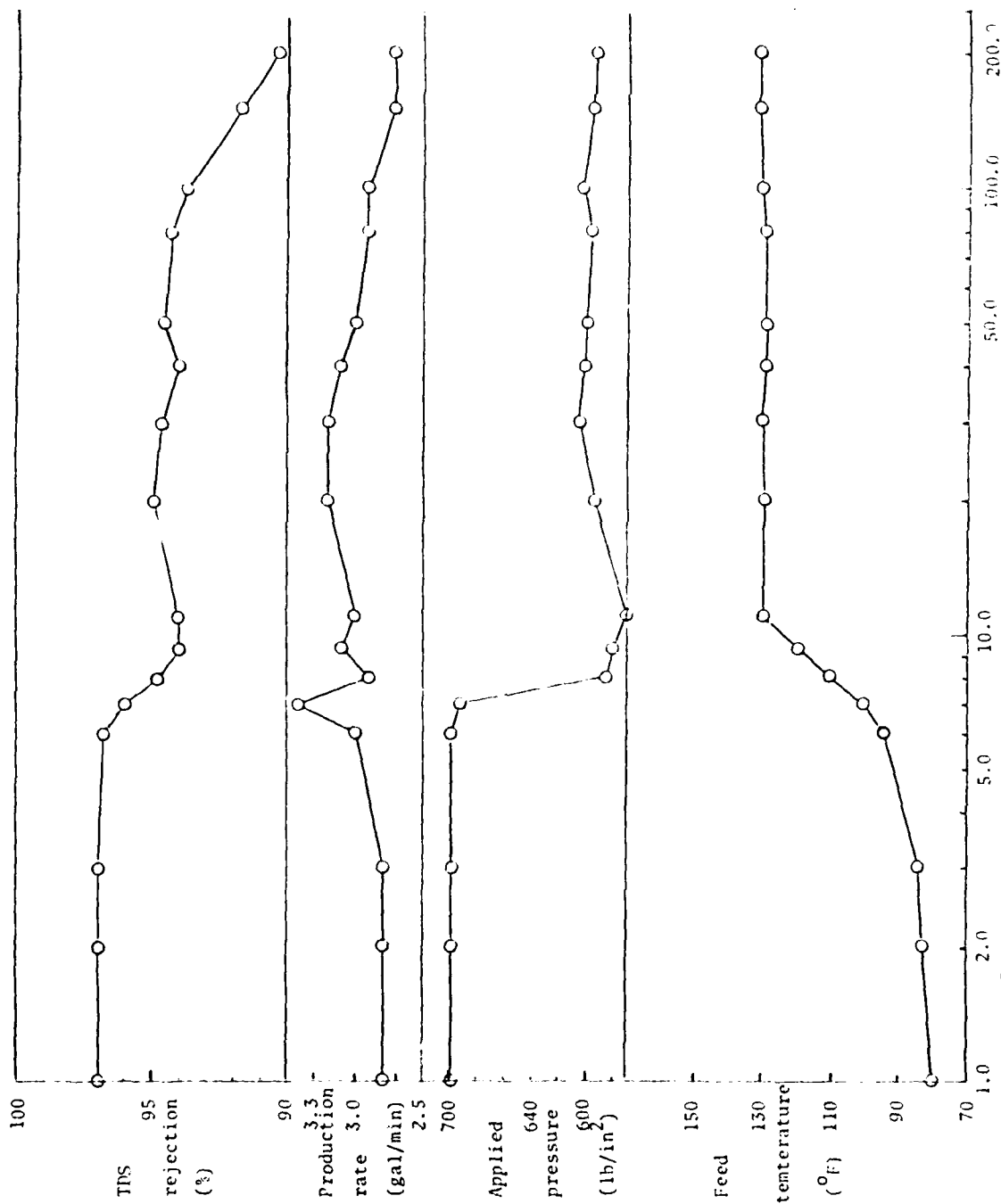


Figure 7. Performance of two TFC 1501 elements in series, cumulative operation (h).

Table 3. Performance Comparison

Date (mo-d)	Hour	Feed Temp. (°F)	Feed Press. (lb/in. ²)	Product Flow Rate (gal/min)	Product Concentration (mg/l)	Rejection (%)	Initial Prod. Rate (%)	Initial Rejection (%)
3-17	8.0	110	586	3.0*	1140	95.6	100.0	100.0
3-25	100.5	130	602	2.9	1170	95.5	96.7	99.9
4-3	200.0	128	600	2.9	1740	93.4	96.7	97.7

* Normalized for applied pressure.

NOTE: The feedwater concentration found by evaporation technique was 26,200 mg/l.

Table 4. Element Performance

Serial Number	Feed Temperature (°F)	Product Flow Rate (gal/min)	Applied Pressure (lb/in. ²)	Product Concentration (mg/l)	Rejection (%)
78761	80	1.2	803	540	98.0
78690	83	1.1	815	500	98.1

NOTE: Above data are average of 1-h operation.

Product concentration was found by the conductivity method. (ASTM D3736-79, para. 9.1.)

Feed salt concentration was 26,500 mg/l.

Feed flow rate was 20 gal/min.

V. CONCLUSIONS

8. Conclusions. It is concluded that:

a. The desalination capability of TFC 1501 elements operated at normal temperatures (80°F to 83°F) does not decrease following 200 h of high-temperature/high-pressure operation and 400 h of exposure to high-temperature brine (130°F).

b. The high-temperature operation (130°F) affects the production rate of the TFC 1501 elements more than the desalination capability. However, with a drop in production rate of less than 5 percent, this drop can be compensated for by operation at a higher pressure up to 1000 lb/in.².

c. Although some telescoping of the elements can be expected during the high-temperature operations, the performance characteristics of the elements will not be degraded.

d. The percent rejection of the TFC 1501 elements is 3 to 5 percent lower when operated on a high-temperature feed (130°F).

APPENDIX

TEST DATA

Reverse Osmosis Test Data

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (μmho)	Product Conductivity (μmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-17	1.0	80	700	17.8	2.8	4.032	41.000	1.200	97.1
3-17	2.0	82	700	17.8	2.8	4.032	41.000	1.200	97.1
3-17	3.0	84	700	17.8	2.8	4.032	41.000	1.200	97.1
3-17	4.0	84	697	17.8	2.8	4.032	41.000	1.190	97.1
3-17	5.0	84	705	17.7	2.9	4.176	41.000	1.140	97.2
3-17	5.8	90	706	17.6	2.9	4.176	41.000*	1.180*	97.1
3-17	6.0	92	702	17.5	3.0	4.320	41.000*	1.300*	96.8
3-17	7.0	100	693	17.3	3.4	4.896	41.000*	1.600*	96.1
3-17	8.0	110	586	17.8	2.9	4.176	41.000*	2.150*	94.8
3-17	9.3	119	580	17.7	3.1	4.464	41.000*	2.400*	94.1
3-17	10.0	123	575	17.6	3.1	4.464	41.000*	2.350*	94.3
3-17	11.0	129	568	17.6	3.0	4.320	41.000*	2.400*	94.1
3-18	11.0	124	703	16.7	4.1	5.904	48.000*	1.820*	96.2
3-18	12.0	124	700	16.7	4.1	5.904	48.000*	1.850*	96.1
3-18	13.0	124	695	16.7	4.0	5.760	48.000*	1.870*	96.1
3-18	13.5	124	603	17.6	3.2	4.608	48.000*	2.250*	95.3
3-18	15.0	128	598	17.5	3.2	4.608	66.000	3.100	95.3
3-18	16.0	128	598	17.5	3.2	4.608	62.000	2.600	95.8
3-18	17.0	129	602	17.6	3.2	4.608	64.000	2.600	95.9
3-18	18.0	129	604	17.7	3.2	4.608	58.000	3.000	94.8
3-18	19.0	129	605	17.7	3.2	4.608	56.000	3.200	94.3
3-18	20.0	129	604	17.8	3.2	4.608	60.000	3.000	95.0
3-18	21.0	129	605	17.6	3.2	4.608	60.000	3.000	95.0
3-18	22.4	130	603	17.6	3.1	4.464	60.000	2.750	95.4
3-18	23.0	130	595	17.6	3.0	4.320	54.000	2.700	95.0
3-19	23.0	124	596	17.7	2.9	4.176	60.000	3.000	95.0
3-19	24.0	126	593	17.6	3.0	4.320	58.000	3.100	94.7
3-19	25.0	129	594	17.7	3.2	4.608	60.000	3.100	94.8
3-19	26.0	130	597	17.6	3.2	4.608	60.000	3.100	94.8
3-19	27.0	130	604	17.6	3.2	4.608	59.000	3.000	94.9
3-19	28.0	129	606	17.6	3.2	4.608	53.000	2.870	94.6
3-19	29.0	130	606	17.6	3.2	4.608	54.000	2.800	94.8
3-19	30.0	130	605	17.7	3.2	4.608	54.000	2.850	94.7

* Conductivity measured at room temperature (77°F).

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (µmho)	Product Conductivity (µmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-19	31.0	130	606	17.6	3.2	1.608	51.000	3.000	94.4
3-19	32.0	130	607	17.7	3.2	1.608	53.000	3.100	94.2
3-19	33.0	130	604	17.7	3.1	1.464	61.000	2.900	95.2
3-19	34.0	130	608	17.7	3.1	1.464	61.000	3.200	94.8
3-19	35.0	130	596	17.6	3.1	1.464	55.000	2.800	94.9
3-20	35.0	125	593	17.8	2.9	1.176	60.000	3.400	94.3
3-20	36.0	126	606	17.8	3.1	1.464	56.000	3.000	94.6
3-20	37.0	128	602	17.8	3.1	1.464	56.000	3.200	94.3
3-20	38.0	129	602	17.7	3.2	1.608	58.000	2.800	95.2
3-20	39.0	130	602	17.7	3.1	1.464	61.000	3.300	94.6
3-20	40.0	129	600	17.6	3.1	1.464	56.000	3.300	94.1
3-20	41.0	129	603	17.6	3.1	1.464	56.000	3.250	94.2
3-20	42.0	130	603	17.6	3.1	1.464	62.000	2.850	95.4
3-20	43.0	129	595	17.6	3.0	1.320	64.000	3.100	95.2
3-20	44.0	130	603	17.6	3.1	1.464	63.000	2.900	95.4
3-20	45.5	129	604	17.6	3.1	1.464	63.000	2.900	95.4
3-20	46.0	129	604	17.6	3.1	1.464	56.000	2.880	94.9
3-20	47.0	129	600	17.6	3.0	1.320	56.000	2.870	94.9
3-21	47.0	124	598	17.7	2.9	1.176	55.000	3.400	93.8
3-21	48.0	126	594	17.8	2.9	1.176	62.000	3.000	95.2
3-21	49.0	127	600	17.7	3.0	1.320	63.000	3.450	94.5
3-21	50.0	129	600	17.6	3.0	1.320	65.000	3.500	94.6
3-21	51.0	130	601	17.6	3.0	1.320	64.000	3.600	94.4
3-21	52.0	130	594	17.7	3.0	1.320	65.000	3.300	94.9
3-21	53.0	130	600	17.7	3.0	1.320	66.000	3.500	94.7
3-21	54.0	129	600	17.8	3.0	1.320	61.000	3.000	95.1
3-21	55.0	130	601	17.8	3.0	1.320	63.000	3.400	94.6
3-21	56.0	131	600	17.7	3.0	1.320	64.000	3.200	95.0
3-21	57.0	130	597	17.7	2.9	1.176	67.000	3.600	94.6
3-22	57.0	120	598	17.8	2.8	1.032	62.000	3.400	94.5
3-22	58.0	120	597	17.8	2.9	1.176	59.000	3.000	94.9
3-22	59.0	120	601	17.8	3.0	1.320	54.000	2.800	94.8

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (μmho)	Product Conductivity (μmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-22	60.0	122	615	17.7	3.2	4.608	56,000	3,000	94.6
3-22	61.0	124	605	17.7	3.0	4.320	58,000	2,800	95.2
3-22	62.0	125	600	17.7	3.0	4.320	60,000	3,000	95.0
3-22	63.0	127	595	17.6	3.0	4.320	59,000	3,300	94.4
3-22	64.0	128	599	17.6	3.1	4.464	58,000	3,600	93.8
3-22	65.0	130	593	17.5	3.1	4.464	67,000	3,550	94.7
3-22	66.0	130	594	17.5	3.1	4.464	64,000	4,000	93.8
3-22	67.0	130	599	17.6	3.1	4.464	66,000	4,100	93.8
3-22	68.0	130	602	17.5	3.0	4.320	65,000	3,650	94.4
3-22	69.0	130	606	17.6	3.0	4.320	63,000	3,700	94.1
3-23	69.0	123	608	17.8	2.9	4.176	58,000	3,800	93.4
3-23	70.0	124	603	17.8	3.0	4.320	56,000	3,600	93.6
3-23	71.0	127	602	17.7	3.0	4.320	58,000	3,000	94.8
3-23	72.4	128	599	17.7	3.0	4.320	60,000	3,500	94.2
3-23	73.0	130	600	17.7	3.1	4.464	60,000	3,000	95.0
3-23	74.0	127	601	17.8	3.0	4.320	56,000	3,200	94.3
3-23	75.0	129	600	17.8	3.0	4.320	58,000	3,600	93.8
3-23	76.0	130	599	17.8	3.0	4.320	60,000	3,200	94.7
3-23	77.0	130	598	17.8	3.0	4.320	60,000	3,400	94.3
3-23	78.0	131	600	17.7	3.0	4.320	60,000	3,500	94.2
3-23	79.0	130	607	17.7	3.0	4.320	59,000	3,300	94.4
3-23	80.0	129	595	17.8	2.9	4.176	58,000	3,300	94.3
3-23	81.0	130	593	17.8	2.9	4.176	66,000	3,700	94.4
3-23	82.0	130	599	17.8	2.9	4.176	57,000	3,750	94.4
3-24	82.0	115	599	18.3	2.4	3.456	54,000	3,000	94.4
3-24	83.0	116	618	18.1	2.6	3.744	52,000	2,500	93.4
3-24	84.0	117	612	18.0	2.6	3.744	56,000	3,000	94.4
3-24	85.5	119	609	17.2	2.7	3.888	58,000	3,500	95.2
3-24	86.5	123	609	17.2	2.8	4.032	63,000	3,400	94.6
3-24	87.5	126	607	17.7	2.9	4.176	60,000	3,400	94.0
3-24	88.5	129	612	17.4	2.9	4.176	62,000	3,400	94.6
3-24	89.5	130	609	17.4	2.9	4.176	60,000	3,600	94.3
3-24	90.5	131	607	17.4	2.9	4.176	60,000	4,000	93.3

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (μmho)	Product Conductivity (μmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-24	91.5	131	607	17.4	2.9	4.176	60,000	3,700	93.8
3-24	92.5	131	610	17.4	2.9	4.176	58,000	4,100	92.4
3-24	93.5	130	610	17.5	2.9	4.176	66,000	4,100	93.8
3-24	94.5	130	610	17.5	2.8	4.032	62,000	4,100	93.4
3-25	94.5	119	605	17.7	2.7	3.888	54,000	3,600	93.3
3-25	95.5	121	609	17.7	2.7	3.888	48,000	3,400	92.9
3-25	96.5	124	610	17.6	2.7	3.888	50,000	3,800	92.4
3-25	97.5	126	610	17.6	2.8	4.032	54,000	4,000	92.6
3-25	98.5	128	605	17.5	2.8	4.032	54,000	4,100	92.4
3-25	99.5	128	600	17.5	2.8	4.032	56,000	3,800	93.2
3-25	100.5	130	602	17.5	2.9	4.176	60,000	3,800	93.7
3-25	101.5	132	598	17.4	2.9	4.176	68,000	4,100	94.0
3-25	102.5	132	599	17.5	2.9	4.176	60,000	4,100	93.2
3-25	103.5	130	612	17.5	2.8	4.032	66,000	4,200	93.6
3-25	104.5	129	610	17.5	2.8	4.032	64,000	4,000	93.4
3-25	105.5	131	607	17.5	2.9	4.032	62,000	3,600	94.2
3-25	106.5	133	605	17.5	2.9	4.176	58,000	3,800	93.4
3-25	107.5	132	610	17.5	2.9	4.176	62,000	3,600	94.2
3-26	107.5	124	605	17.4	2.9	4.176	62,000	3,700	94.0
3-26	108.5	124	608	17.7	2.7	3.888	56,000	3,200	94.3
3-26	109.5	124	610	17.8	2.8	4.032	56,000	3,000	94.6
3-26	110.5	126	609	17.8	2.8	4.032	57,000	3,000	94.7
3-26	111.5	128	604	17.8	2.7	3.888	58,000	3,000	94.8
3-26	112.5	130	602	17.7	2.7	3.888	58,000	3,000	94.8
3-26	113.5	131	600	17.8	2.8	4.032	60,000	3,400	94.3
3-26	114.5	132	600	17.7	2.8	4.032	62,000	3,600	94.2
3-26	115.5	131	600	17.8	2.7	3.888	62,000	3,400	94.5
3-26	116.5	131	600	17.7	2.7	3.888	60,000	5,900	90.2
3-26	117.5	132	619	17.6	2.9	4.176	62,000	4,200	93.2
3-26	118.5	131	604	17.6	2.7	3.888	65,000	3,900	94.0
3-26	119.5	130	610	17.8	2.7	3.888	65,000	3,900	94.0
3-27	119.5	125	607	18.0	2.7	3.888	65,000	4,100	93.7
3-27	120.5	126	596	17.8	2.6	3.744	63,000	3,900	93.8

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (µmho)	Product Conductivity (µmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-27	121.5	129	595	17.6	2.6	3.744	58,000	4,100	92.9
3-27	122.5	130	591	17.5	2.6	3.744	58,000	4,300	92.3
3-27	123.5	130	592	17.5	2.6	3.744	65,000	3,850	94.1
3-27	124.5	129	590	17.5	2.6	3.744	64,000	4,200	93.4
3-27	125.5	129	610	17.7	2.7	3.888	66,000	4,000	93.9
3-27	126.5	130	606	17.7	2.7	3.888	66,000	4,200	93.6
3-27	127.5	130	606	17.7	2.7	3.888	68,000	4,200	93.8
3-27	128.5	130	605	17.8	2.7	3.888	63,000	4,200	93.3
3-27	129.5	131	605	17.8	2.7	3.888	63,000	4,400	93.0
3-27	130.5	131	607	17.8	2.7	3.888	60,000	4,400	92.7
3-28	131.5	122	600	17.8	2.6	3.744	61,000	3,450	94.3
3-28	132.5	125	615	17.8	2.8	4.032	58,000	3,600	93.8
3-28	133.5	127	612	17.7	2.8	4.032	58,000	4,000	93.1
3-28	134.5	128	609	17.7	2.8	4.032	58,000	4,100	92.9
3-28	135.5	130	607	17.7	2.8	4.032	61,000	4,100	93.3
3-28	136.5	131	603	17.7	2.8	4.032	64,000	4,100	93.6
3-28	137.5	130	604	17.7	2.7	3.888	60,000	4,000	93.3
3-28	128.5	130	602	17.7	2.7	3.888	64,000	4,000	93.8
3-29	138.5	124	612	17.8	2.7	3.888	56,000	3,800	93.2
3-29	139.5	125	611	17.8	2.7	3.888	55,000	4,000	92.7
3-29	140.5	125	602	17.8	2.7	3.888	56,000	3,600	93.6
3-29	141.5	126	628	17.7	2.9	4.176	60,000	4,000	93.3
3-29	142.5	128	610	17.8	2.9	4.176	60,000	4,100	93.2
3-29	143.5	130	604	17.7	2.8	4.032	71,000	4,000	93.4
3-29	144.5	131	604	17.7	2.8	4.032	60,000	4,000	93.3
3-29	145.5	130	606	17.8	2.8	4.032	60,000	4,000	93.3
3-29	146.5	128	608	17.8	2.7	3.888	60,000	4,000	93.3
3-29	147.5	130	603	17.7	2.7	3.888	61,000	4,100	93.3
3-29	148.5	131	601	17.7	2.8	4.032	61,000	4,150	93.2

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (µmho)	Product Conductivity (µmho)	Rejection (%)
					(gal/min)	(gal/d)			
3-29	149.5	131	592	17.6	2.7	3.888	65,000	4,300	93.4
3-29	150.0	132	593	17.6	2.7	3.888	58,000	4,800	91.7
3-30	150.0	124	598	18.0	2.6	3.744	56,000	4,800	91.4
3-30	151.0	126	595	18.0	2.6	3.744	57,000	4,400	92.2
3-30	152.0	126	601	17.9	2.7	3.888	56,000	4,400	92.1
3-30	153.0	128	611	17.9	2.8	4.032	56,000	4,200	92.5
3-30	154.0	130	601	17.7	2.8	4.032	60,000	4,500	92.5
3-30	155.0	130	602	17.7	2.7	3.888	60,000	4,300	92.8
3-30	156.0	128	604	17.7	2.7	3.888	60,000	4,100	93.2
3-30	157.0	130	596	17.7	2.7	3.888	60,000	4,200	93.0
3-30	158.0	131	609	17.7	2.8	4.032	60,000	4,200	93.0
3-30	159.0	131	593	17.6	2.7	3.888	60,000	4,300	92.8
3-30	160.0	130	613	17.8	2.8	4.032	60,000	4,100	93.2
3-30	161.0	130	609	17.8	2.7	3.888	64,000	4,500	93.0
3-30	162.0	130	605	17.8	2.7	3.888	63,000	4,100	93.5
3-31	162.0	122	605	18.0	2.7	3.888	59,000	5,000	91.5
3-31	163.0	124	606	18.0	2.6	3.744	60,000	5,100	91.5
3-31	164.0	126	605	18.0	2.6	3.744	60,000	4,800	92.0
3-31	165.0	128	602	18.0	2.7	3.888	60,000	4,400	92.7
3-31	166.0	130	600	18.0	2.7	3.888	61,000	4,400	92.8
3-31	167.0	129	603	18.0	2.7	3.888	61,000	4,400	92.8
3-31	168.0	129	600	18.0	2.6	3.744	62,000	4,500	92.7
3-31	169.0	128	600	18.0	2.6	3.744	60,000	4,600	92.3
3-31	170.0	129	611	17.9	2.7	3.888	60,000	4,000	93.3
3-31	171.0	130	613	17.7	2.8	4.032	60,000	4,000	93.3
3-31	172.0	130	604	17.7	2.8	4.032	58,000	4,300	92.6
3-31	173.0	130	608	17.7	2.8	4.032	60,000	4,500	92.5
4-1	173.0	124	611	17.7	2.8	4.032	54,000	5,000	90.7
4-1	174.0	126	614	17.8	2.8	4.032	54,000	4,200	92.2

Reverse Osmosis Test Data (Cont'd)

Date (mo-d)	Cumulative Operation (h)	Feed Temp (°F)	Feed Pressure (lb/in. ²)	Brine Flow Rate (gal/min)	Product Flow Rate		Feed Conductivity (µmho)	Product Conductivity (µmho)	Rejection (%)
					(gal/min)	(gal/d)			
1-1	175.0	128	609	17.7	2.8	4.032	54,000	4,400	91.9
1-1	176.0	129	605	17.7	2.8	4.032	56,000	4,300	92.3
1-1	177.0	130	609	17.8	2.9	4.176	56,000	4,600	91.8
1-1	178.0	130	605	17.7	2.8	4.032	62,000	5,000	91.9
1-1	179.0	130	608	17.7	2.8	4.032	58,000	4,800	91.7
1-1	180.0	130	607	17.8	2.8	4.032	59,000	4,700	92.0
1-1	181.0	130	605	17.8	2.8	4.032	60,000	4,800	92.0
1-1	182.0	130	600	17.8	2.8	4.032	64,000	4,600	92.8
1-1	183.0	129	598	17.8	2.7	3.888	66,000	4,600	93.0
1-1	184.0	129	596	17.7	2.7	3.888	62,000	4,800	92.3
1-2	184.0	124	606	17.7	2.7	3.888	60,000	4,800	92.0
1-2	185.0	125	602	17.8	2.7	3.888	58,000	4,400	92.4
1-2	186.0	126	598	17.7	2.7	3.888	60,000	4,800	92.0
1-2	187.0	128	617	17.7	2.9	4.176	60,000	4,200	93.0
1-2	188.0	130	615	17.7	2.9	4.176	58,000	4,600	92.1
1-2	189.0	131	599	17.5	2.8	4.032	62,000	5,100	91.8
1-2	190.0	131	597	17.5	2.8	4.032	60,000	5,400	91.0
1-2	191.0	130	601	17.5	2.8	4.032	60,000	4,400	92.7
1-2	192.0	130	600	17.5	2.7	3.888	61,000	4,800	92.1
1-2	193.0	129	604	17.5	2.7	3.888	61,000	4,600	92.5
1-2	194.0	129	601	17.5	2.7	3.888	60,000	4,600	92.3
1-2	195.0	128	602	17.6	2.7	3.888	63,000	4,800	92.4
1-3	195.0	124	600	17.8	2.8	4.032	60,000	5,800	90.3
1-3	196.0	124	600	17.8	2.7	3.888	60,000	5,400	91.0
1-3	197.0	126	600	17.9	2.7	3.888	62,000	5,400	91.3
1-3	198.0	129	602	17.9	2.8	4.032	60,000	5,000	91.7
1-3	199.0	130	602	17.8	2.8	4.032	62,000	5,400	91.3
1-3	200.0	131	592	17.6	2.7	3.888	55,000	5,600	90.3

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